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Frequency Tuning of Symmetric Colliding Pulse Mode-Locked Laser through Asymmetric Biasing Intra-Cavity Phase Modulators

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In this paper we report a multimode interference reflector (MIR)-based linear cavity mode-locked laser (MLL) operating in the telecom C-band with a repetition rate of 30 GHz as shown in Fig. 1. A pair of intra-cavity electro-optic phase modulators (EOPM) enables spectral tuning of the optical and the photo-detected RF spectrum. As an asymmetric bias voltage increases up to 6 V, the RF frequency shift reaches 3 MHz. This photonic integrated circuit (PIC) was rapidly prototyped using generic photonic integration technology platform via industrial Multi-Project Wafer (MPW) run [1].

(a)

(b)

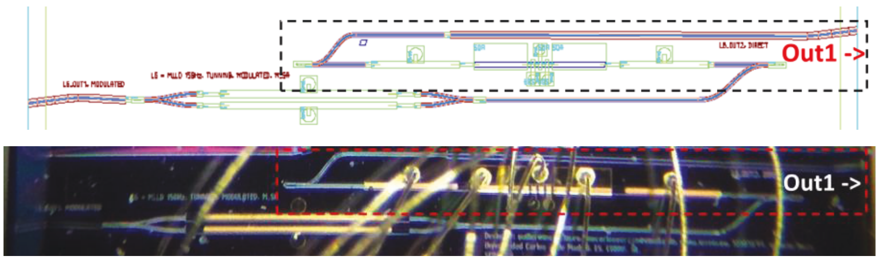

Fig. 1. (a) Layout (b) Microscope view of the proposed PIC

MLLs generating short optical pulse and wide coherent optical frequency comb have attracted interest in areas such as telecommunications, sensing systems and microwave photonics. The feasibility to on-chip integrate semiconductor optical amplifiers (SOA), saturable absorbers (SA), EOPM and passive waveguide devices such as MMI couplers and MIR allows for advanced controllable manipulation [2,3].

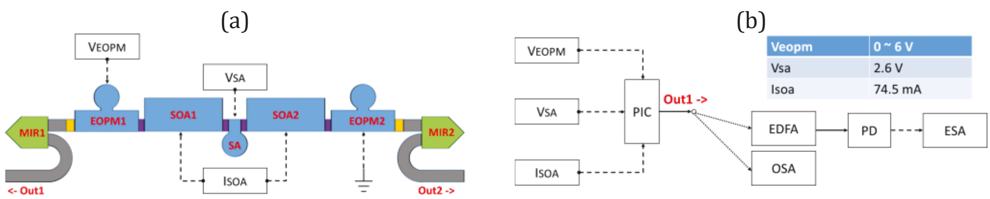

Fig. 2. (a) Schematic of PIC (b) Block diagram of experimental setup

In Fig. 2(a) the core MLL is depicted schematically, corresponding to the area bounded by the dashed line in Fig. 1. It is of the symmetric colliding pulse mode-locking configuration [4] surrounded by a pair of identical EOPMs. The left EOPM was biased (V_{EOPM}) from 0 to 6 V while the right EOPM was always grounded. Two SOAs shared one current source (I_{SOA}) of 74.5 mA and the middle SA was fed with a reverse bias voltage (V_{SA}) of 2.6 V. As presented in Fig. 2(b), the emitted optical signal was measured with a lensed fiber to couple light from the angled waveguide output Out1. By using either an optical or an electrical spectrum analyser (OSA, ESA) the spectra were monitored and collected. An EDFA was deployed, followed by a photodiode (PD) and the ESA.

At V_{EOPM} = 0 and 6 V the optical spectrum was recorded as presented in Fig. 3(a) and (b), respectively. In Fig. 3(a) the comb has a signal-to-noise ratio (SNR) of 30 dB and side-mode-suppression ratio (SMSR) of 15 dB. The mode spacing is 0.24 nm equal to 30 GHz. Similarly, in Fig. 3(b) the SNR is still around 30 dB but the SMSR degrades to less than 10 dB. The shape of comb becomes a sharp triangle, not as same as the flatter plateau in Fig. 3(a). In Fig. 3(c) a series of beat tones produced by the PD are exhibited where the influence of V_{EOPM} is visualized. As V_{EOPM} increases, the peak moves to the left and the shift is gradually weaker. The blue (6V) peak is at 29.5198 GHz and the red (0V) is at 29.5224 GHz, separated by 3 MHz.

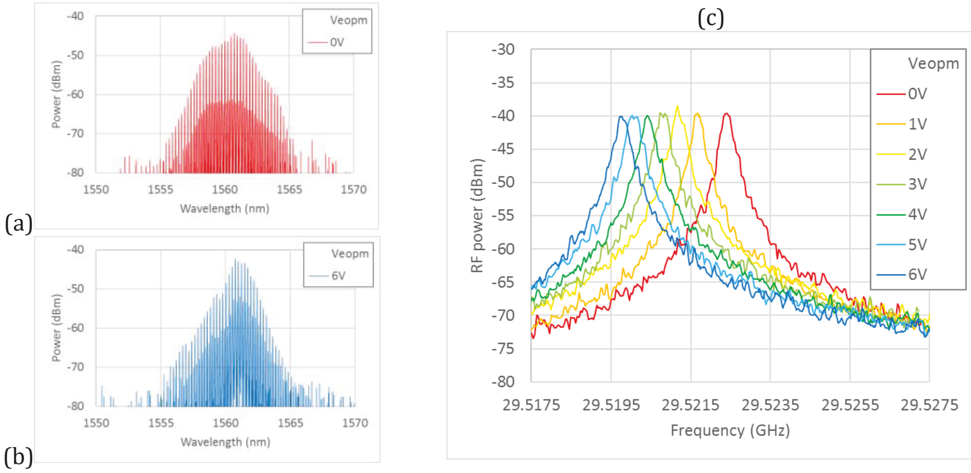

Fig. 3. (a) Optical spectrum when V_{EOPM} = 0 V (b) Optical spectrum when V_{EOPM} = 6 V (c) Electrical spectrum of beat tones when V_{EOPM} = 0 - 6 V

The spectral tuning has been experimentally demonstrated with an asymmetrically biased pair of EOPM. Since the symmetric colliding pulse mode-locking is inherently in conflict with the asymmetric biasing condition [5], further theoretical investigation on the tuning mechanism as well as the limited tuning range should be performed.

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